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Requirements for Deck Joints in Highway Structures

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Requirements for Deck Joints in Highway Structures

Synopsis: The paper describes the requirements which were developed for deck joints for the Ontario Highway Bridge Design Code. The Code provisions apply to prefabricated joint assemblies which accommodate translation and/or rotation.

The basic philosophy of the Code is that the minimum number of joints be used consistent with the need for articulation and drainage of the structure. Sources of movement and loads on deck joints are discussed in detail.

Two types of joint are recognized: those which are sealed against penetration by water and open joints in which the flow of surface drainage is permitted. Requirements for each type of joint are given. Requirements for durability, skid resistance, attrition, noise, ease of inspection, maintenance and modification are expressed qualitatively. Requirements for installation, permissible gaps and anchorage are expressed quantitatively. Factors influencing the selection of the type of joint are given.

Keywords: bridge decks; durability; highway bridges; joint sealers; joints (junctions); loads (forces); maintenance; specifications.

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INTRODUCTION

Most design codes, including the AASHTO specifications (1), contain few requirements for deck joints. It is neither practicable nor desirable for bridge designers to produce individual designs for the deck joints. Where conditions permit, considerable benefits in economy and performance can be expected from the use of standard joint details. Consequently, most of the prefabricated joint assemblies now used in highway structures are proprietary products, and these have been catalogued in detail (2,3). Many of the joints have evolved over the years and have been subject to periodic refinement by the manufacturer's staff. There is little uniformity between material specifications or the amount of laboratory and field testing on each type of joint. Acceptance criteria differ widely from jurisdiction to jurisdiction.

Although the deck joints are an integral part of the bridge structure and should be carefully considered early in the design stage, this rarely happens. Too often, a proprietary joint is selected from a manufacturer's catalogue at the last moment, improperly installed by unskilled labour and not maintained. Where a competing system is actually installed under an "or approved equal" provision in the contract documents, the joint may bear little resemblance to that shown on the plans. Appropriate modifications in anchorage or block-out details may not always be made. Consequently, it is not surprising that the performance of deck joints has often not been satisfactory. Typical failures of deck joints and the adjacent pavement are shown in Figures 1, 2 and 3. A survey of practices and performance of deck joints in the United States in 1977 (3) found that many proprietary joints were not performing as intended. This has resulted in public agencies having to assume responsibility for costly repairs or replacement of defective systems.

In 1976, the decision was made to write the Ontario Highway Bridge Design Code (OHBDC), the first edition of which was published in 1979 (4). The Code is written in a limit states format

and is based on a new design load (5). The chapter on bearings and deck joints required the preparation of new material which, while defining performance requirements, must be capable of immediate implementation. The paper describes the rationale and the requirements for deck joints in the OHBDC.

DESIGN PHILOSOPHY

A deck joint is defined (4) as "a structural discontinuity between two elements, at least one of which is a deck element, designed to permit relative translation and/or rotation between the two." This definition includes all joints in the deck or between the deck and the abutments at which movement can take place, but excludes construction joints.

The basic philosophy which has been adopted is that the minimum number of joints be used consistent with the need for articulation of the structure. The approach to eliminate as many joints as possible has been taken because of the generally poor performance of deck joints. There are considerable benefits to be derived from eliminating joints entirely, where possible, as might be the case for curved structures or those which have flexibility in the support system, such as, with slender or hinged columns. An example of a curved structure without expansion joints is shown in Figure 4. The structure acts like a bow with the superstructure fixed at both abutments. Movement at intermediate supports is accommodated by sliding bearings.

Where deck joints are required, two types are specifically excluded by the OHBDC because of unsatisfactory service records. Any joint which relies upon the adhesion of a flexible material to seal the joint has been found prone to failure within a few years of installation. Similarly, joints placed directly in concrete without provision for armour at the edges of the roadway surface, fail because of spalling of the concrete. This type of failure was common when it was normal practice to install compression seals in direct contact with a concrete deck slab.

Deck joints divide conveniently into those which are designed to be sealed or waterproof and open joints which are designed to permit the free flow of water through the joint. All joints must be designed so that none of the components fail at serviceability limit states and sealed joints remain watertight. Since deck joints do not affect the safety of a structure, some damage can be tolerated from conditions exceeding serviceability limit states since it would be uneconomic to design joints for ultimate limit states. Acceptable damage is considered to be that which can be repaired while the deck remains in service, even though one or more lanes may be closed to traffic to permit the repairs to be carried out.

SOURCES OF MOVEMENTS AND LOADS

Movements in a structure result from either loading conditions or a change in volume of the components of the structure. The magnitude of the movement must be calculated for each structure since it depends upon the nature of the structure and its response to static and dynamic forces. The most common sources of loads on deck joints are direct impact of wheels, temperature, and those caused by soil conditions which result in the movement of supports. Conversely, some joints, particularly compression seals or those which accommodate movement by the shear deformation of an elastomer, can impose substantial forces on the structure which must be included in the design of the structure. This characteristic of compression seals and certain proprietary joints may prevent substitution of these joints for those which do not exert forces on the structure.

A checklist, which has been found to be convenient method of ensuring that all factors affecting the magnitude of movements and loads have been considered in design, is as follows:

(a) Properties of the materials in the structure, including coefficient of thermal expansion, modulus of elasticity, Poisson's ratio, creep and shrinkage.

(b) Effective temperature range of the structure.

(c) Sizes and properties of the structural members.

(d) Method and sequence of construction.

(e) Tilt, settlement and movement of supports.

(f) Construction tolerances.

(g) Static and dynamic response of the structure.

(h) Interaction of the forces to which the structure may be subjected, including dead and live loading, wind, earthquake and earth pressures.

(i) Structural restraints.

Joints which are considered "fixed" may be fixed against translation, but not rotation. Since the deck joint does not coincide with the flexural centroid of the main deck supporting members, flexural deflection of the member results in rotation at the joint as shown in Figure 5. Failure to accommodate this rotation has been a common cause of leakage and deterioration at "fixed" joints.

The plan geometry of a bridge superstructure is an important factor in determining the movements which take place at different

points in the structure. Bridges which are straight and narrow in plan will generally exhibit movements along their centreline in response to changes in temperature. Bridges which are curved in plan or with skew joints have two components of movement at deck joints, a longitudinal component along the centreline of the superstructure and a transverse component perpendicular to the longitudinal centreline as shown in Figures 6 and 7. The transverse component can cause serious problems with some types of expansion devices, for example, finger joints (sometimes called tooth or comb joints). Binding of the joint can result in large forces on the joints, bearings and abutments with corresponding reactions at intermediate piers.

To determine the actual movement of a bridge superstructure at all the points of attachment of the superstructure and from all sources of movement, the position of the neutral or stationary point must be established. The position of the stationary point depends upon the geometry of the superstructure, the location of the piers and bearings and their relative shear stiffnesses, and the type of dimensional change. For straight structures, the stationary point is generally located on the longitudinal centreline of symmetry as shown in Figure 8. In curved structures the stationary point will generally not be located on the longitudinal centreline and may be outside the plan of the superstructure. Movements are then towards and away from the stationary point as shown in Figure 9. The calculation of the location of the stationary point can be quite difficult for complex structures. Detailed explanations for determining the location of the stationary point have been presented (6, 7, 8).

FUNCTIONAL REQUIREMENTS

The first step towards a performance specification is a statement of the required results. Four such requirements for deck joints can be defined.

(a) The components of the joint must accommodate the translation and rotation of the structure at the joint.

(b) The joint must provide for the passage of traffic across the joint without significantly impairing the riding quality of the pavement surface. It must not be a safety hazard to the road user, including pedestrians and cyclists where permitted.

(c) The joint shall be maintenance-free for the design life of the structure.

(d) Deck joints must be constructed and detailed such that they prevent damage to the deck, bearings, piers and abutments from water, deicing chemicals and other foreign materials, either by preventing water from passing through the joint or by permitting water to drain through the joint in such a manner that damage to the deck, bearings, pier or abutment does not occur. The selection of an open joint will normally

require particular attention to the details of components of the structure other than the joint itself to satisfy this requirement.

Other features, which are either desirable or have been found necessary for good long term performance can also be defined without imposing unnecessary process limitations on the construction of the joint:

(a) All materials in the joint shall be durable.

(b) No surface of the joint exposed to traffic shall be such as to cause skidding and all parts shall be resistant to attrition and the impact of traffic, especially snowplows, where used.

(c) The joint shall not vibrate nor amplify traffic generated noise and the components shall be arranged such that they do not translate or rotate under the direct application of wheel loads.

(d) All components of the joint shall be accessible for inspection and maintenance and shall be replaceable except for anchorages permanently attached to the structure.

(e) The joint shall be constructed so that it can be elevated, by modification or addition, to accommodate future overlays.

(f) The joint shall not impart stress on the structure except where the structure has been designed to withstand these stresses.

Having defined the requirements for deck joints qualitatively, the final step in the production of a performance specification is to express the requirements quantitatively such that they can be measured and verified. It is this step which has proven so difficult. A draft performance specification for waterproof deck joints up to 100 mm movement capacity has been prepared (3). Responsibility for selection of the joint and extensive pre- and post-installation testing was placed on the contractor. The draft also contained an optional requirement for an in-service performance guarantee. The provisions require a major change in design and contractual procedures for the selection, purchase and installation of deck joints and have not been implemented.

The ultimate stumbling block in the development of a performance specification is the division of responsibility between the agency, the contractor and the joint supplier. The joint supplier will not accept responsibility for the performance of a joint unless he is also responsible for the installation. The contractor can only be held responsible if he is also responsible for the selection of the joint sealing system. However, the performance of the joint is also determined by the behaviour of

the total bridge structure, which is largely a function of design, and by the agency's maintenance procedures, such as snowplowing, over which the contractor has no control. Consequently, an approach to ensure satisfactory performance through the use of a performance guarantee is fraught with administrative and legal difficulties. It is also unlikely to produce the desired result since the intent is easily circumvented. Where there is a delayed payment provision, the costs to the contractor can be passed on to the agency either by increasing the bid cost of the joint or by distributing the costs associated with the guarantee among the other bid items. If defects develop and the cost of the repairs is likely to exceed the delayed payment, there is nothing to prevent the contractor from waiving the holdback and leaving the agency with the responsibility for repairing the joint.

In Ontario, a system of prequalification of proprietary deck joints has been used for several years. Physical tests on the joint materials are conducted and joint performance is evaluated, largely on the basis of engineering judgement, against the qualitative requirements defined in the OHBDC. It is recognized that none of the joints currently in use completely satisfy all of the requirements. A list is published of those joints which most nearly meet the requirements and which are approved for use. The joints are classified within broad categories, such as, compression seals, strip seals and cushion seals. The designer then specifies the use of any approved joint from whichever categories are suitable for a particular installation.

The contractor is held responsible only for defects in materials and workmanship, responsibility for the former being passed along to the joint supplier. A performance guarantee is not considered feasible because required standards and acceptance criteria have not been defined adequately. There would also be serious difficulties in enforcement and, in any event, the cost is ultimately borne by the agency. The present procedure of controlling the selection of the joint type, while allowing competing systems, where possible, has been found the most economic and workable system to date. Some specific requirements have been developed for gaps and for open and sealed joints in an attempt to ensure satisfactory performance without inhibiting new product development.

The maximum permissible gap at the serviceability limit states is limited to 100 mm for deck joints with a single opening, and to 80 mm for each opening in deck joints with multiple openings. The gap is measured perpendicular to the joint at the deck surface. These limits are based on experience and have been found to be the maximum which can be permitted consistent with maintaining an adequate quality of ride across the joint for user comfort and the safety of vehicle loads. Other jurisdictions limit the maximum gap to as little as 65 mm (9). While improvements in ride quality result from keeping the maximum gap as small as possible, this requires the use of more multiple opening joints which cost considerably more than joints

with single openings. Since incompressibles become trapped in many types of sealed joint, the minimum gap should be not less than 20 mm in order to prevent the transfer of forces through the debris in the joint. Consequently, limits on the minimum gap also increase the maximum gap for the same movement capacity.

Open Deck Joints

Under certain conditions, an open deck joint can provide an effective and economic solution. Satisfactory performance depends upon the provision of an effective deck drainage system, control of flow of surface drainage through the joint and disposal of the run-off from the site. The success of open joints in the past has been limited by damage to the portion of the structure beneath the joint from debris and run-off, especially in areas where deicing salts are used. Wet dirt would often accumulate on the flanges of steel beams or around bearings and sustain corrosion. Chlorides would penetrate concrete surfaces causing the scaling of inadequately air-entrained concrete and the corrosion of embedded reinforcement. The amount of deterioration can be minimized by removal of the accumulated debris by routine washing followed by spot repainting, but this has rarely been done in practice.

It is essential that surface run-off and roadway debris not be permitted to accumulate on any part of the structure beneath the joint. The use of troughs and drain pipes has not been successful because they become clogged with debris. In cold climate areas pipes often freeze up. Although troughs can be cleaned out, pipes often cannot. Deterioration of bearing seats can be achieved by placing bearings on pedestals and by avoiding surfaces with a slope of less than 3 horizontal to 1 vertical. Washout of slope paving and the ponding of water around column bases are problems which have arisen where provision for the disposal of run-off has been inadequate.

Sealed Joints

Sealed deck joints are required to seal the surface of the deck, including curbs, sidewalks, medians and, where necessary, barrier or parapet walls, against the seepage of moisture and other contaminants through the joint. It is also a requirement that the geometry of the joint be such as to prevent the accumulation of water and roadway debris in the joint. Metal to metal sliding surfaces have not performed satisfactorily largely because of the effects of vibration, the accumulation of debris and the fact that they cannot be sealed effectively. The presence of debris and, in the winter months, of ice, has been found to restrict the movement capabilities of joints and displace thin membrane seals. Where the movement of the joint is accommodated through the change in geometry of a thin gland or membrane, this should not be in direct contact with vehicles to prevent failures from wear and puncture by incompressibles.

Proprietary joints claimed to be "self-cleaning," have been found to be no less vulnerable to damage by accumulated debris than other types of joint.

Deck joints having elastomeric components in direct contact with the deck surface, do not provide adequate support for the edges of the deck wearing surface. Nosings of epoxy mortar or similar material are sometimes used between the edges of the deck surface and the joint to try and prevent spalling of the edge of the deck.

The chief factors in determining whether to use an open or a sealed joint are cost and the location of the site. The total cost of each system must be compared and, for open joints, this includes the cost of disposing of surface run-off. The total costs of sealed joints may include the cost of providing for additional forces on the structure, and an increase in maintenance costs and frequency of inspection.

In general, open joints are well suited to secondary highways where little sand and salt is supplied during winter maintenance operations. Sealed joints tend to be more suited to urban areas where the costs of providing for the surface run-off can be high.

INSTALLATION

It is normal practice to include, in tabular form, the required installation settings throughout the probable installation temperature range on the contract plans. Factors, such as, creep, shrinkage, elastic-shortening and the sequence of construction, need to be taken into account in calculating the installation settings. A method of relating shade temperature to the effective temperature, which is defined as that temperature which controls the thermal response of the bridge, has been developed (10). A simpler method, which has been found adequate, is to take the effective or installation temperature as the mean shade air temperature for the 48 hours prior to joint installation for concrete structures, and for the previous 24 hours for composite structures with a concrete deck slab and steel beams. The difference reflects the fact that concrete is a poor thermal conductor and changes in the effective temperature occur more slowly in concrete structures than steel structures. More sophisticated methods are rarely necessary since the temperature will change during the time taken to install the joint. There is also a danger that more complex procedures will not be understood by the contractor's personnel and the inspectors. Where the joints are installed in concrete, temporary connections must be released as soon as the concrete is placed to prevent distress in the concrete from the movement of the structure.

Field observations have shown a lower incidence of damage in joints where concrete end dams are at least 400 mm wide since a wider concrete surface appears to reduce the dynamic load on the joint. A detail which has been found satisfactory is illustrated

in Figure 10 for the case where a compression seal is used. A similar detail can be used with any other type of joint. The steel angles between the end dam and the bituminous concrete is necessary to prevent spalling of the concrete. Vent holes of approximately 5 mm diameter on 250 mm centres are required in the top of all angles to prevent air entrapment when placing the concrete. A minimum angle thickness of 12 mm is desirable (11). The 200 mm gap beneath the joint facilitates inspection and improves ventilation so that the ballast wall and the ends of the beam are less susceptible to damage if leakage should occur.

In areas where snowplows are used, the joint must be recessed a minimum of 5 mm from the surface of the deck, curb, sidewalk and wall for protection against snowplow damage. Too great a recess increases noise levels and decreases the quality of ride. Steel ribs may be used to raise the plow as it passes over the joint. Joints with a skew which coincides with the skew of the snowplow blade, typically 30 to 35°, are particularly vulnerable to snowplow damage. Additional precautions, such as, the provision of plates across the top of the joint, should be taken in such cases.

Where a bedding material is used to ensure complete contact between the bottom of the joint and the deck surface, a material which becomes rigid is preferred. The bedding compound should be plastic at the time of installation and the joint placed before the material sets. Sufficient load should be placed on the joint to squeeze out excess material and seat the joint at the required elevation. Flexible bedding materials, such as, elastomers, have been found susceptible to creep which can result in vibration of the joint and the failure of some types of anchorage.

It is preferable that the number of field splices in sealed joints be kept to a minimum. Where splices are necessary, their location should be shown on the plans to prevent the use of short sections of material which are susceptible to leakage at the splices.

ANCHORAGE

Each side of the joint must be anchored to the deck or abutment so as to transfer all static and dynamic loads from the joint assembly to the structure. It is normal practice to design anchorages by neglecting any contribution from concrete under the joint. Field experience and laboratory testing (11, 12) have shown that the following minimum anchorage requirements should be satisfied:

(a) Where the deck joint assembly is attached by reinforcing bars cast into concrete, the total cross-sectional area of the bars on each side of the joint should be not less than 1600 mm^2/m and the bar spacing be not less than 250 mm. Perforated plates giving an equivalent anchorage

capacity may also be used. The anchorage system should be fixed to the main structural reinforcement. In the case of perforated plates or loops, this can be done by passing transverse bars through the loops.

(b) Where the joint assembly is attached directly to the steel superstructure by welding or bolting, the weld or bolts should have an ultimate capacity of not less than 600 kN/m. The spacing of the bolts or between welds should not exceed 250 mm.

(c) Any other method of anchorage should have a capacity at least equal to (a) or (b) above.

Anchor bolts set in concrete have not been found satisfactory and tend to work loose under dynamic loading (9). Loosening of the bolts has been observed with both friction type anchors and with bolts set in grout. Anchor bolts installed nearer the face of the joint than the first transverse reinforcing bar have also caused spalling of the concrete at the joint.

CONCLUSIONS

The paper describes qualitatively and, in some cases, quantitatively, requirements for the design, construction and installation of deck joints in highway structures. Some of the more important considerations are as follows:

1. A minimum number of joints should be used consistent with the articulation and drainage system of the structure. Consideration of the deck joints is necessary early in the design stage of a structure.

2. Careful calculation of the loads and movements at all points of attachment of the superstructure is necessary for the proper selection of the deck joint system.

3. Deck joints must be safe, durable, and accommodate the required movements. They must not cause deterioration of the structure beneath the joint.

4. A performance guarantee is not a panacea for the unsatisfactory performance of some proprietary joints.

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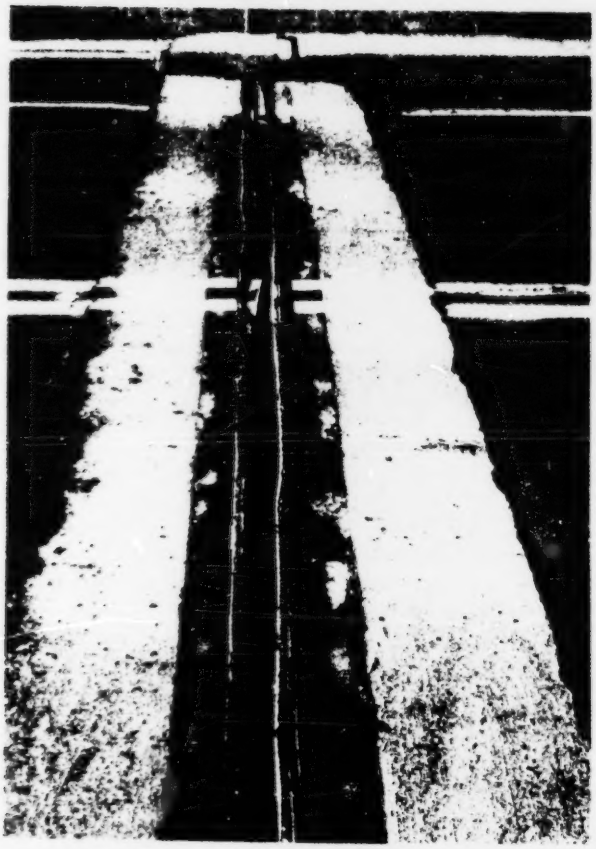


Fig. 1--Modular joint--The center steel section has been hit by a snowplow and the rubber seal has failed in several places. The steel sliding plate in the curb has been installed facing the wrong direction. The wide concrete end dams are in good condition

Fig. 2--Rubber cushion joint--The joint has been damaged by snowplows, the seal has been punctured by a flare base. The anchor bolt plugs have failed and the bituminous concrete adjacent to the joint has spalled

Fig. 3--Compression seal--The narrow concrete end dams have failed, the joint is not armored, and is not watertight

Fig. 4--A 598 m long structure in Niagara Falls, Ont., Canada, built without expansion joints

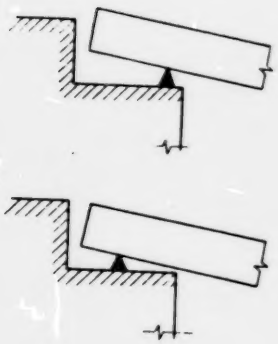


Fig. 5--Rotation at a deck joint resulting from flexural deflection

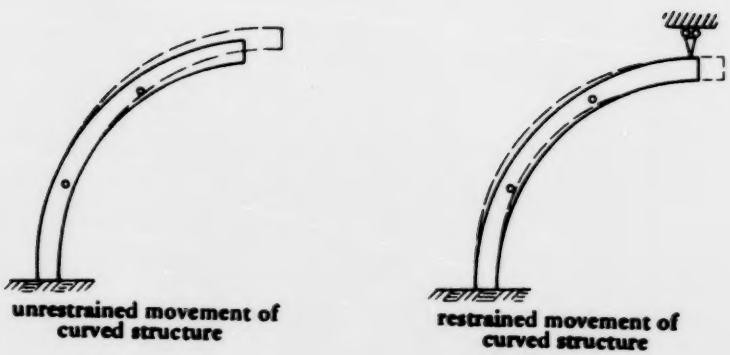


Fig. 6--Response of curved structures

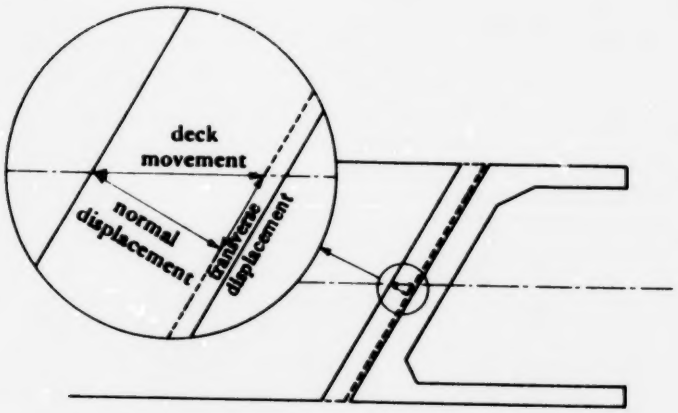
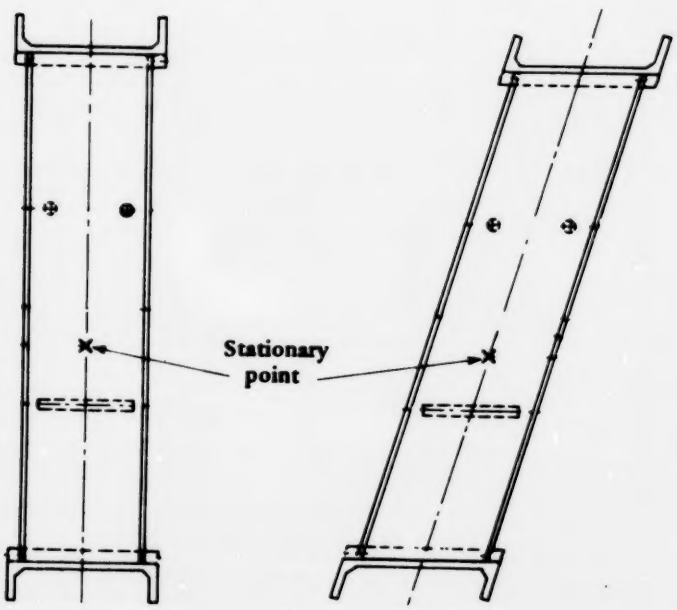


Fig. 7--Normal and transverse displacements across a skewed joint



(a) RIGHT SUPERSTRUCTURE (b) SKEWED SUPERSTRUCTURE

Fig. 8--Stationary point in straight and skewed superstructures

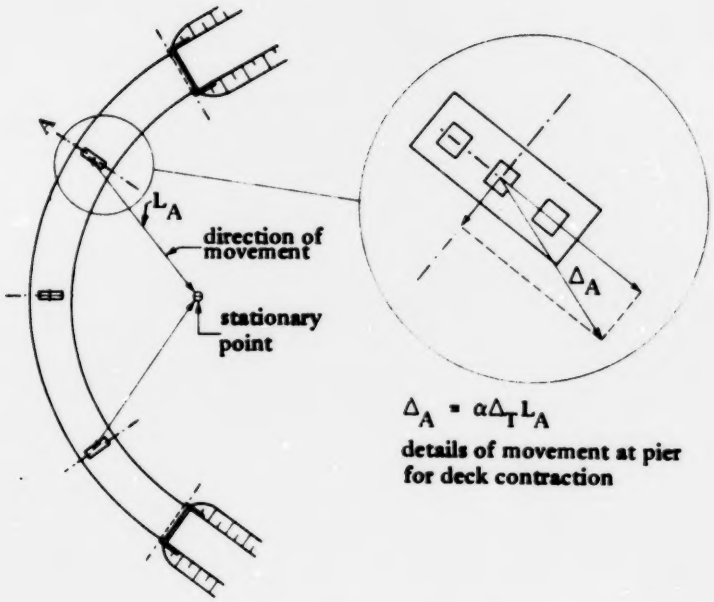


Fig. 9--Stationary point in curved structures

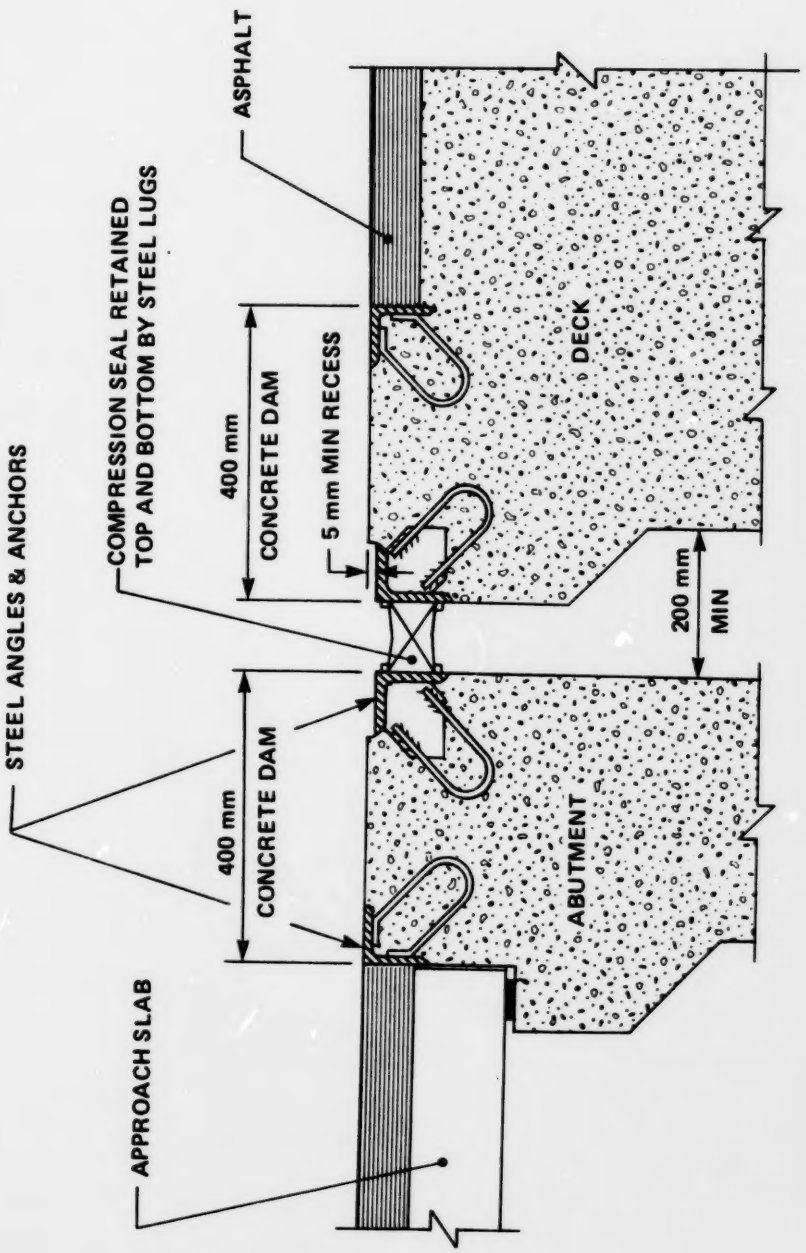


Fig. 10--Typical detail for installation of a deck joint assembly